

The Absorption of Sodium Vapor

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HISTORICAL.

THE fluted absorption spectrum of sodium vapor was first observed by Roscoe and Schuster in 1874. Subsequent investigations were made by Liveing and Dewar in connection with their work on the reversal of lines of metallic vapors, and also by Wood. Nine bands were photographed in the green and some others were observed visually in the red region. These bands they found consisted of a great number of fine lines, more or less regularly spaced along the region of absorption.

The fluorescence of the same vapor, excited by white light, was studied by Wiedemann and Schmidt¹ in 1896.

In 1904 Wood and Moore² made an investigation of both the absorption and fluorescence, endeavoring to find how the two were related, also to determine the effect of changing the wave-length of the exciting light. They proved conclusively that the two are in every way complementary, *i. e.*, an absorption band in one corresponds in position to a fluorescent band in the other. The presence of hydrogen was found to magnify greatly the appearance of the fluorescence, and to cause its disappearance when the pressure was above a few centimeters. Since these phenomena are so closely related it is perfectly natural to suppose that a study of the effects of pressure upon absorption will throw some light upon the mechanism of fluorescence.

Quite recently A. Dufour³ has found that the absorption of bromine vapor and some other gases is greatly modified by the presence of some chemically inert gas above atmospheric pressure, and although fifty or more lines were found to shift, others were not.

¹ Wied. Ann., VII., 447, 1896.

² Phil. Mag. (6), 1904.

³ Compt. Rendus, 145, 757-758, 1907.

Dufour investigated separately, and under the same conditions the effect of hydrogen, CO and air, all producing the same effect. This points to a purely mechanical effect as distinguished from a chemical one.

Wood in 1906¹ found that the absorption spectrum of sodium vapor is fluted in the presence of hydrogen at atmospheric pressure and above, but that at very low pressures the fluted form entirely disappears. These observations were made under comparatively low dispersion; and at the suggestion of Professor Wood the investigation to be described was begun in order to study the same phenomena with apparatus having higher dispersion.

The effects which will be considered in this paper should not be confused with the usual "pressure shifts" studied by Humphreys. It is probable that they are more nearly analogous to the phenomena described by Wood in the case of mixtures of mercury vapor with hydrogen, nitrogen, helium and other chemically inert gases in varying proportions.²

In this paper it was shown that the shape and even the position of an absorption band is greatly changed by the presence of a foreign gas at low pressures. It was first noticed when the vapor was in the presence of hydrogen, and thinking that it was due to some sort of chemical combination, he repeated the same experiment with nitrogen and helium. The effect was the same. There is much evidence brought out in this investigation that certain of the lines of sodium behave in a similar manner. The pressures are in most cases between 1 mm. and 760 mm., far below the pressure at which any true "pressure-shift" can be observed.

OBJECT OF THE RESEARCH.

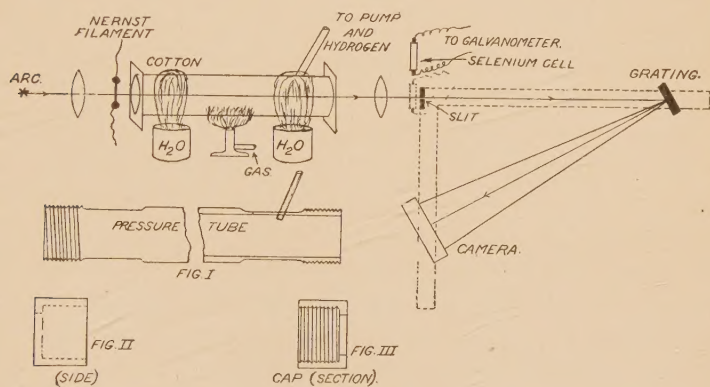
1. To observe and record the fine structure of the absorption spectrum of sodium vapor.
2. To determine the influence of variation in pressure upon the fluted absorption spectra.

¹ Phil. Mag. (6), 12, 1906.

² Astrophys. Jl., XXVI., No. 1, July, 1907,

METHOD OF INVESTIGATION AND RESULTS.

Apparatus.—In brief the apparatus consisted of a piece of seamless steel tubing $1\frac{1}{4}$ inches in diameter, 18 inches in length and wall $\frac{1}{16}$ inch in thickness, closed with glass plates hermetically sealed with sealing wax. About an inch from one end of this tube a hole was drilled into which was brazed a piece of $\frac{1}{4}$ -inch brass tubing, through which the tube was exhausted. A small pan was placed in the central portion of the tube in which the sodium was confined. This kept the molten metal from running to the ends. This tube was employed for all of the work up to atmospheric pressure. For pressure higher, another one was constructed of the same type, except that the walls were much thicker, and the glass windows held on by threaded caps. It is shown in Fig. (1) of the diagram.



Figs. 1, 2, 3.

The internal diameter is $1\frac{1}{8}$ inches, thickness $\frac{1}{8}$ of an inch. Each end was threaded to receive the caps, which held the glass windows. This tube similar to one used by Wood.¹

Just inside of the threaded portion on each end was turned down in a lathe to a thickness of $\frac{1}{8}\frac{1}{2}$ of an inch, around which were wrapped the cotton pads. These were necessarily larger than those used on the low pressure tube, on account of the high temperature to which the tube must be raised to obtain the fluted effect at the higher pressures. This left 6 inches of the middle for heating area which

¹ Phil. Mag. (6), 1904.

would withstand the high pressure when the tube was at a bright red heat.

The caps for the ends were made of cast brass, turned out and threaded to fit rather tightly, a flange being left to hold the glass windows which were made with a special tool so that the fit would be close. They were taken from a piece of plate glass $\frac{3}{16}$ inch thick. Black sealing wax was used on account of its comparatively high melting point and hardness when cool.

As a source of light, the carbon arc was employed throughout, on account of its great brilliancy, care being exercised to keep the image of the positive pole on the slit.

In order to maintain a definite density of vapor it was necessary to keep the temperature of the tube constant. This was accomplished by using an ordinary Bunsen burner supplied with a modified type of fish tail tip. The electric furnace was first employed, but on account of lack of resistance, properly divided, a small enough increase or decrease of current could not be obtained. Besides, the furnace is very slow in reaching a steady state, requiring from one half to one hour at low temperature. It gives much more uniform layer of vapor, as the heating is on all sides. When great density is desired the use of Bunsen burners is more satisfactory, distillation to the colder parts of the tube taking place much less rapidly. To keep air currents from blowing the flame from the tube, and to give a more uniform temperature on all sides the flame was enclosed in an asbestos sheath, with a tin cap placed on the tube just above it.

A part of the work which did not require high dispersion was done on the 14-ft. concave grating. Later on the 21-ft. concave grating was employed, as the other proved unequal to the task of showing the small details of the spectrum.

The hydrogen used was produced by action of hydrochloric acid on zinc. Great trouble was at first experienced in high pressure work by the formation of fog in the tube, which made the atmosphere inside absolutely opaque for one or two hours. It was found however, that this fogging was the direct effect of impurities in the hydrogen. After elimination of these by passage through well-known solutions, little fog was observed.

METHODS FOR KEEPING CONSTANT DENSITY.

To determine when the density was at a certain stage, one of two methods was employed.

The first was used when taking a series of exposures in which the pressure was varied from 1 mm. to 760 mm. It was desirable to keep the actual absorption unchanged, noting the effect upon the flutings as a whole. Since the formation of flutings is due to the loss of only a few lines in the heads, it is natural to assume that, if the total absorption is unchanged, so is the density of the vapor, regardless of the change from bands into flutings due to variations in pressure of the gas. In order to determine the total absorption by the vapor, a selenium cell—kindly provided by Dr. Pfund—a Nernst filament and a sensitive galvanometer were used. In regulating the density of the vapor the light from the filament was passed through the tube and allowed to fall upon the selenium cell. The galvanometer deflection was noted; the filament and cell were removed, and the absorption spectrum photographed. If, now, this same density is desired for a different pressure of the gas, the filament and cell are replaced and the temperature of the tube varied until the galvanometer deflection is the same as before. In regulating the density for a certain state of absorption the Nernst filament was placed behind the tube so that when the galvanometer became steady, the filament and cell were removed, and the arc replaced. A photograph is taken, and for a change of pressure the above is repeated. A different deflection would mean simply a different density.

The increase of absorption upon increase of pressure of the foreign gas is due to the fact that the gas prevents the rapid diffusion of the metallic vapor, with the result that the partial pressure of the sodium is increased; in other words, more vapor is present in unit volume. It is therefore necessary to cool down the tube in order to reduce the absorption.

The second method for keeping the density constant was employed when working on the *D* lines. It consisted simply in focusing the *D* lines of the third order on a piece of ground glass, while the *D* lines of the second order were being photographed. Their widths were marked on the ground glass when the pressure was

1 mm., and it is assumed that this width of the absorption line marks a definite density of the vapor. Therefore, if a constant density is desired during any series of observations, all that is necessary is to maintain this width constant by slight changes in the temperature of the tube.

ABSORPTION SPECTRUM UNDER HIGH DISPERSION AT 1 MM.
PRESSURE.

The small pan was filled with metallic sodium and pushed to the middle of the tube, and the glass plate cemented to the ends. The tube was then exhausted and heated until the absorption lines appeared in the green and red. The *D* lines at this stage were about 1 Angström unit in width. The density was increased by gradually raising the temperature, and the absorption spectrum photographed at five different stages. The width of the *D*-line absorption region at the fifth stage was about 20 Angström units. The photographs show that the lines are of unequal intensity. In the first spectrum, which was taken with vapor of considerable density, certain groups of absorption lines have fused together, forming what appear to be broad bands with sharp edges. The sharpness and narrowness of the transmitted regions between the absorption lines is especially noticeable, the bright lines seeming quite as narrow as the iron lines. The general appearance is indeed quite similar to that of an emission spectrum. There is, even in this case, a slight suggestion of a grouping of the lines into bands. As we shall see later on, the admixture of hydrogen or some other inert gas brings out the fluted bands very distinctly by altering the relative intensity of the absorption lines. Figs. 1 and 2, Plate I., represent the green of the second order and Fig. 1 the red in the first order enlarged six times. Broken down under such high resolving power they are found to consist of an immense number of fine lines, extending from λ 6500 to λ 4500. They appear very sharp in the blue and blue-green regions, but as we approach the greenish-yellow they become less sharp, assuming a rather hazy form when λ 5150 is crossed. Although the dispersion is quite sufficient for studying individual lines, some of them still present a very complex form. This is seen in Fig. 4, Plate I., which also represents a portion of the orig-

inal negative enlarged nearly six times. The groups at λ 4615.5, 4624.5 and many appear as if composed of several narrower ones superimposed.

The red of the second order could be studied only visually owing to the mounting of the grating. It presented an even more beautiful appearance than the green and blue. The broad dark lines seen with lower dispersion are easily resolved, many of them being composed of from ten to fifteen very fine hair-like lines. These are spaced in irregular groups, one or two broader ones being placed in between. They are much finer than those in the green and are in much closer proximity. These were at their best when the *D* lines were just fusing together.

This fine line absorption spectrum of sodium vapor is not confined to the red and green, but immediately on each side of the absorbed *D*-line region the lines show nearly as fine and numerous as in the red. A rough estimate of the total number of absorption lines given by sodium vapor, at low pressures, is about 8000 or 10,000. No doubt higher dispersion will reveal many more.

Although the red could not be photographed in the second order on account of the limit to the movement of the 21-ft. grating, a good idea could be gotten from photographs taken in the first order. They appear very much as do those in the green.

Wratten and Wainwright plates (panchromatic) were used and found very satisfactory in this region.

EFFECT OF INTRODUCING HYDROGEN.

1. The appearance of the flutings as a whole as the pressure is increased from 1 mm. to 11 atmospheres.
2. The effect upon individual lines and groups of lines.

FLUTING WITH PRESSURE 1 MM. TO 760 MM.

In studying the appearance of the flutings as the pressure of the gas changes, a series of photographs were made varying the pressure from 1 mm. to 760 mm., by seven steps, keeping the actual degree of absorption the same. This was accomplished by the method already described with the selenium cell and sensitive galvanometer. Two sets of photographs were taken, each with a

definite density of vapor. The principal set was with a density such that the flutings were just entering their best stage, and when the central ones in the green were partially absorbed. All show the same thing, viz., the extent to which the bands become fluted varies directly with the pressure up to atmospheric, which seems to be a critical value; as the appearance remains practically the same, for an increase of pressure amounting to several atmospheres.

The photographs at 1 mm. pressure, taken in the first order with the 14-ft. grating, presents a series of irregularly spaced fine lines from λ 4600 to λ 5200, from which point they appear more regular, breaking up into a group of three small bands between λ 5100 and λ 5136, six even more regular ones between λ 5180 and λ 5220, and three others between λ 5240 and λ 5270. All of these lines, except those included in the three named sets of bands, show a tendency toward fluting, as soon as the pressure is increased above a few centimeters, the fine lines composing the heads of the flutings dropping out or becoming diminished in intensity. Points which at 1 mm. show as absorption lines gradually become replaced by transmitted regions, smoothing out the irregularities, causing the spectrum as a whole to acquire a uniform fluted appearance.

The three sets of small bands between λ 5200 and λ 5300 simply grow more feeble, until at 60 cm. pressure they fade almost completely, the spectrum becoming nearly continuous. The series of fine lines between λ 4700 and λ 4800 not only flute regularly, but begin to fade away, leaving no trace of lines below λ 4730.

The second series of photographs with greater absorption shows the same general effect, except that the extreme ends of the green absorption region between λ 4700 and λ 4800; and between λ 5100 and λ 5320, come out more strongly owing to the greater absorption. The group at λ 5200 was still visible at 760 mm. This was also true on the violet side, *i. e.*, the fine line flutings pushing out further into the shorter wave-lengths. The central large flutings between λ 4850 and λ 4950 become much weaker, as the pressure is increased. In order therefore to photograph them and the more intense bands at the same time a mechanical screen was employed. This was placed in front of the camera box, and operated by a small motor. It consists of a piece of cardboard with a section cut out about the

length of the portion of the spectrum needing more exposure. This, when moved back and forward in front of the plate shades in the brighter portion of the field into the darker. Absorbing screens were tried but with little success. All possess too much general absorption and further, no combination could be found that would give a narrow transmitted band in the portion of the spectrum desired.

In the red at the lowest pressure there appears between λ 6000, and λ 6100, beginning indistinctly at the former, a series of eight bands or semi-flutings, which aside from becoming a little more distinct, undergo little change as the pressure is increased. These correspond to the invariable bands observed in the greenish-yellow region. Reaching atmospheric pressure there are eight much longer ones which appear between λ 6100 and λ 6500; being, however, more sharply defined.

Close examination of the photograph shows a slight lack of definition at 76 cm. compared to that at 2 mm. This will be discussed under head of "Effect upon individual Lines," but it is mentioned here as a forerunner to the discussion of the fluting under high pressure.

EFFECT OF VARIATIONS IN PRESSURE UPON FLUTING. ONE TO TEN ATMOSPHERES.

Series of exposures were made with the pressure varying from one to ten atmospheres, increasing from one and one-half to two atmospheres each time. The result is shown in Fig. 2, Plate II. No special trouble was experienced in getting the spectrum to flute up to three atmospheres. But above this it required two good Bunsen burners, with strong blast, well inclosed, to bring the flutings out distinctly. This made the tube a bright cherry-red color, and after reaching 10 atmospheres, fear of breakdown limited a further increase of pressure.

There was a very faintly fluted spectrum obtained at the last named pressure, but in the process of printing this is lost, and therefore is not shown here, but it affords a good indication of what might be expected at higher pressures.

The spectrum at atmospheric pressure as was mentioned above

shows a lack of sharpness. This is also true at higher pressures. At nine atmospheres there remains only a well fluted continuous spectrum. This is perfectly distinct at this pressure, although at ten atmospheres scarcely any trace of it appears.

The behavior in the red was observed visually, under the same pressures and similar changes noticed, except that the flutings and lines disappear at much lower pressures than do those in the green. Owing to the fact that the vapor was made under such high pressure and consequently so dense, very little light could be gotten through the tube above five atmospheres, and photographs could not be obtained in the second order. Exposures in the first required from three fourths to one and one half hours, and the red region, even with a comparatively wide slit could scarcely be seen, only presenting a weak continuous appearance. At ten atmospheres the absorption is very general in its nature, practically all of the red-yellow and blue-green is gone, leaving the violet much stronger than the rest.

EFFECT OF PRESSURE UPON INDIVIDUAL LINES AND GROUPS OF LINES.

In this portion of the investigation the second order of the 21-ft. grating was used where possible.

The tube being cleaned out and a lump of sodium inserted, it was exhausted to a pressure of 1 mm. An exposure was made when the absorption lines were most numerous and the definition greatest. Then hydrogen was admitted to atmospheric pressure, the tube being left connected to the gas supply. This was done to make sure that the pressure in the tube did not rise on account of the property possessed by metallic sodium when heated, to occlude great quantities of hydrogen.

A photograph was taken when the conditions of absorption were as near as possible the same as at the lower pressure. The result is shown in Figs. 1 and 2 of Plate I., Fig. 4 being given to show the width of the absorbed region at the *D* lines, at density used. The heads of the flutings can now be measured accurately and are given below. With lower dispersion they appear as "single line" heads, and were measured as such by Moore, but, as can be seen from the

data, they consist of one, two and sometimes three lines, some of them having no definite head. The form of these heads is given along with that produced at 760 mm., so that some idea can be gotten of the phenomena taking place.

The lack of definition mentioned in the preceding part is seen to be much more pronounced in the green than in the red, especially at the longer wave-lengths. Instead there is more actual absorption at 760 mm., many of the strongest bright lines being cut out completely, and feebler ones making their appearance. These remain sharp compared with the yellow, green and blue absorption lines near λ 5700 and λ 4600 respectively. The intermediate regions between λ 4650 and λ 4920 show only the fluting effect. The two spectra have nearly the same intensity at this point, but at λ 4600 comparatively little light is absorbed.

APPEARANCE OF HEADS OF FLUTINGS IN GREEN. WAVE-LENGTHS ACCURATE TO .01 ÅNGSTRÖM UNIT.

Vacuum of 1 mm. p.		Atmospheric Pressure.	
1.	4766.71 66.97 doublet.	Fuses together, no shift.	
Slightly broken effect at 4782.92 and 4792.95			
2.	4819.75 heavy single line. Very irregular fluting.	Spreads some and shifts to 4819.85	
3.	4837.15 37.31 doublet.	1 Shifts.	4837.26
		2 Does not shift.	4837.31
4.	4865.15 very heavy. 4865.30 weak.	Breaks into triplet. 4865.04 65.30 65.50	
Consists of a series of irregular lines.		Breaks into series small doublets in creasing in size to head.	
5.	4894.48 heavy single.	Shifts to 4894.37	
5.	Semi break at 4911.40	Breaks into symmetrical doublet. Resembling Zeeman effect. 4911.84 and 20.1	
		The whole fluting consists of irregular groups of doublets and triplets.	
6.	4932.41 .54 doublet.	Fuse into cone at 4932.38	

7.	No definite lines.	Transformed into hazy triplet at 4962.04 .23 .47
8.	5000.94 heavy. 1.12 weak.	Lines irregular all through Forms hazy doublet 4000.86 5001.10 1 shifts. 2 widens toward violet. Very irregular series shown in Fig. 2, Plate III
9.	5039.92 40.08 triplet. .18	Contracts to close doublet almost inseparable at 5039.98
10.	Is weak and hard to notice 5079.65 5076.89 doublet.	Remains doublet, both shifting symmetrically to 5079.56 5079.89

There are besides these the seven small bands, or groups of lines which produce a sort of "rolling" effect, and appear like this:

These are found in the blue between λ 4703.46 and λ 4810.16. They are not apparent at vacuum, but are brought out at 76 cm. The wave-lengths are given below:

4703.46	4741.59
4704.78	4767.22
4716.10	4810.11
4727.89	

The bands found in the yellow green, and unaffected at atmospheric pressure are given below:

5100.5	5184.1	5240.1
5112.6	5196.2	5252.1
5124.7	5208.3	5264.2
5136.8	5223.5	5276.3

These bands in the violet are clearly noticeable, at eleven atmospheres, while those in the yellow green stand fairly well up to six atmospheres.

Flutings in the
Red and Orange.

5997.82

6019.23

6042.05

6080.40

6099.64

6119.12

6141.01

6168.00

Well pronounced at vacuum, only slightly brought out at pressure.

6179.23	Slightly visible at vacuum but brought out clearly' by pressure.
6185.06	
6219.87	
6276.29	
6329.44	
6373.88	Not at all visible at vacuum, but strongly fluted by pressure.
6417.50	
6464.62	
6512.36	
6559.64	
6610.30	

In the orange the two spectra are about equal intensity, and the lines are fused together, but as the pressure is raised to 760 mm. the intensity is much less, and the fluting is more pronounced.

One of the chief characteristics of the absorption spectrum is the doublet formation observed at atmospheric pressure. A small part of this can be seen very clearly in Fig. 3, Plate I., between λ 5001 and λ 5025, which represents a portion of the original negative enlarged about two and one half times. In the red part of the spectrum the reverse is true, that is, this doublet formation is more evident at 1 mm. pressure, than at 760 mm. Between wave-lengths λ 5900 and λ 6200 this is very common, especially near λ 6100.

This characteristic of doubling by the lines extends up to 6600 and appears only at very low pressures, disappearing at atmospheric pressure.

In the enlarged portions represented by Figs. 1 and 2, Plate I., Fig. 3 shows at 760 mm. absolutely no regularity, whereas at 1 mm. the groups between λ 5001 and λ 5025, break up or are transformed into the regular series shown.

Many of the lines are displaced as much as .15 A.U. for a change of 760 mm. One line out of a group will move to the red, the others remaining in this same position.

Nearly all of those which shift at all none are in the direction of longer wave-length, although many are displaced toward the violet. This apparent change of position does not differ in amount between wave-lengths λ 4600 and λ 5100, the average being about .11 of an Angström unit. At λ 5006.2 can be plainly seen the difference in the absorption at 760 and 2 mm. respectively.

Judging from the green absorption region one would immediately look for similar changes in the red. But, in fact, although all of

the lines were examined, there can be noticed only a few instances of unsymmetrical broadening or apparent shifts.

In view of the fact that so many changes occur in the absorption spectrum of sodium vapor, in the presence of hydrogen as the pressure is changed from 1 mm. to 760 mm., some sort of chemical combination seems altogether possible. Consequently to decide this point the hydrogen was replaced by nitrogen. A fresh piece of sodium was used and the tube cleaned before taking a photograph. The tube while heated was exhausted; air was allowed to enter the tube, was again exhausted, etc., several times, each time allowing air to enter the tube at atmospheric pressure. On account of the great affinity of sodium for oxygen little else remained in the tube except nitrogen. A photograph was obtained under the same conditions as with hydrogen, and the two spectra showed exactly the same results line for line.

STUDY OF THE D LINES.

The effect of pressure upon the *D* lines is much different from that on the other absorption lines of sodium. Photographs were taken with pressure varying from 1 mm. to 12 atmospheres, the density being kept constant by the method already described. Except for a slight decrease in sharpness no change in the spectra was observed as the pressure was changed from 1 mm. to 760 mm. This can be seen only when one of the *D* lines is about 2 A.U. in width. Any greater density causes the absorbed space to become so broad and hazy that this effect can not be detected, and with very low density, even at the highest pressures, the *D* lines should remain very fine and sharp.

Fig. 3, Plate II., shows the effect of high pressure. There seems to be an unsymmetrical broadening, which extends to the longer wave-length. It can be best described in this way. If we heat up the tube at 760 mm. pressure until *D* is about 2 Angström units in width, then remove the burner, and allow the tube to cool, the two *D* lines of course will be seen to die away symmetrically, getting narrower until they disappear. If, now, we raise the pressure up to 10 atmospheres, and again observe the decay of the lines, the fine *D*'s will be seen just on the edge of the shadow which vanishes

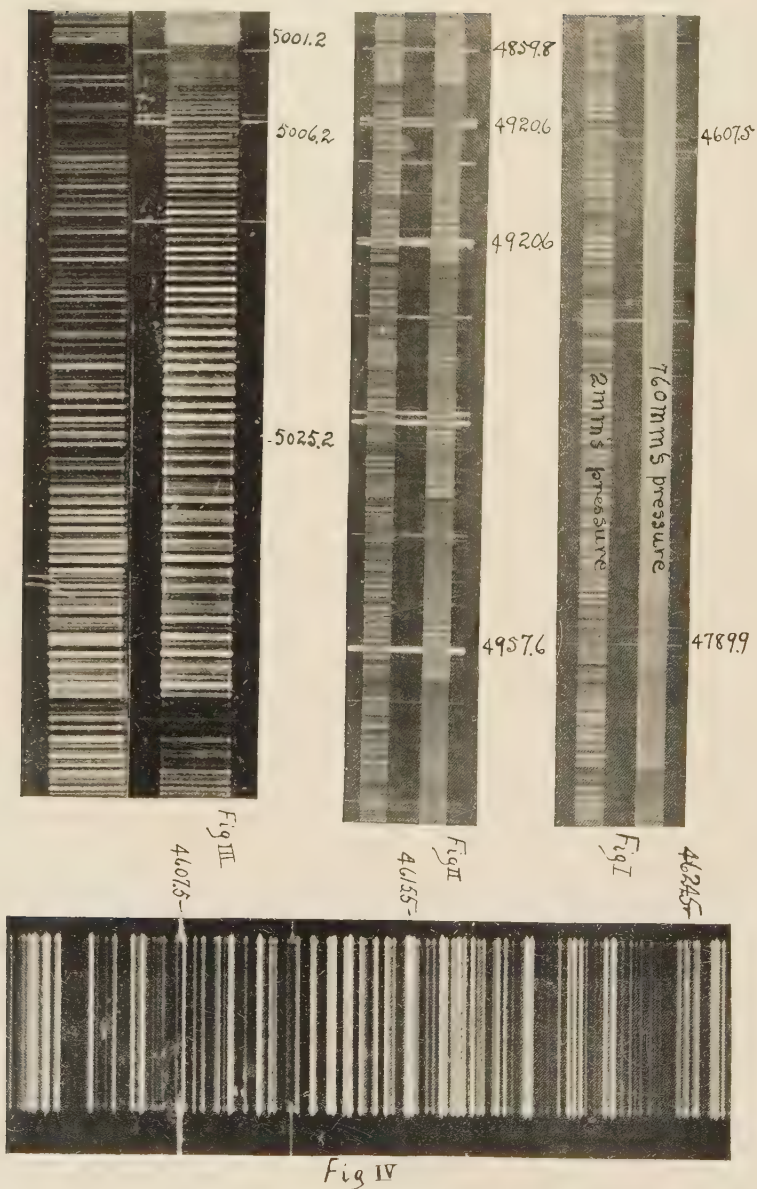


PLATE I. CLINKSCALES.
The Absorption of Sodium Vapor.

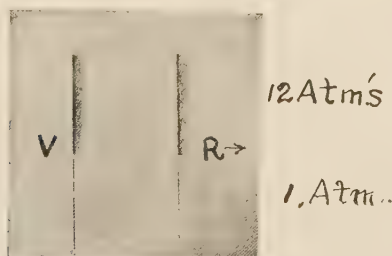
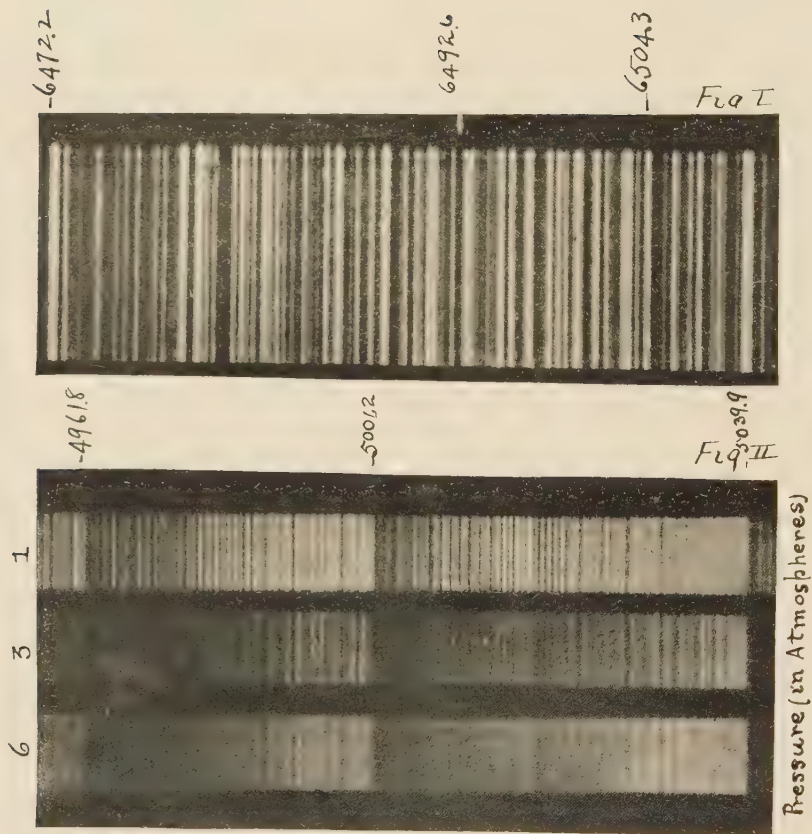


Fig III

PLATE II. CLINKSCALES.
The Absorption of Sodium Vapor,

some time before the *D* lines themselves. It is much easier to observe this change than to photograph it, but an excellent idea can be gotten from the figure on Plate II.

This effect is very much the same as that observed by Julius in working with anomalous dispersion of sodium vapor, where he causes unsymmetrical broadening of the *D* lines, either one or both, by merely changing locality of heating. The source of heat was obtained by an electric current passing through two nickel wires running parallel through the tubes containing the vapor.

The heating in the present instance was a small flame under the tube. By using an electric the point could be immediately decided. But for lack of time the author would have tried this.

SUMMARY.

The results of the investigation may be summed up as follows:

1. Under high dispersion the absorption spectrum of sodium vapor in the region investigated is found to consist of approximately 10,000 lines, the region of absorption extending mainly from λ 4500 to λ 6700, which was as far as results were obtained.

2. The bands can be divided into two classes: first, those in which the extent of fluting varies directly as the pressure is increased from 1 mm. to 760 mm., and second those which are not affected much by pressure.

3. As the pressure is increased to 8 atmospheres, the absorption spectrum becomes continuous in appearance, the fluting disappearing almost completely at 10 atmospheres.

4. The transformations of the lines which occur as the pressure is raised from 1 mm. to 760 mm. may be briefly stated as follows:

(a) Many of the lines between λ 4600 and λ 5100 shift their positions as much as .15 A.U. caused either by unsymmetrical broadening or by the pressure of the foreign gas.

No such effect is observed in the red part of the spectrum.

(b) A single line is changed into a doublet, and a doublet into a triplet, although the reverse is more often true.

(c) The whole spectrum is characterized more or less by a doublet formation, which is more noticeable in the shorter wave lengths at 760 mm., and in the longer wave-lengths at low pressures.

(*d*) The *D* lines, when *D* is about one Angström unit in width, are unsymmetrically broadened nearly 5 A.U. under 12 atmospheres pressure, but at extremely low pressure, remains very sharp and shows no broadening.

5. No difference can be noticed in the absorption spectra for the different gases used.

In conclusion I wish to acknowledge my great indebtedness to Professor Wood, who suggested the work and under whose direction it was carried out.

JOHNS HOPKINS UNIVERSITY,
June, 1908.

BIOGRAPHICAL SKETCH.

George Brownlee Clinkscales was born in the city of Anderson, Anderson County, South Carolina, March 16, 1882. After receiving his early education in the preparatory schools of Columbia, S. C., he entered Clemson A. & M. College, Clemson College, S. C., in 1898, pursuing the electrical engineering course, and graduating in 1902. During the year 1903-1904 he did engineering work in Wilmington, N. C., and Spartanburg, S. C. In 1903 he entered Vanderbilt University, Nashville, Tenn., taking up mathematics, physics and electrical engineering. The following year, 1904-1905, he taught mathematics at Wofford College, Spartanburg, S. C., entering the Johns Hopkins University in 1905, where his principal subject has been physics, the first subordinate applied electricity and the second subordinate mathematics.

